Doppler Analysis of an Indoor University-Hall

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***Abstract*—An analysis of delay-Doppler characteristics in the presence of moving people is presented for short-range communications in an indoor environment. Channel sounding measurements have been carried out at 3.6 GHz in a crowded university-hall during short and long breaks between courses. The measurements reveal a difference between the RMS Doppler spread of both breaks, indicating a distinctive power distribution of their Doppler spectra. In addition, there is a significant contrast between the Doppler characteristics of the co- and cross-polarizations. Looking at the behavior of both the Doppler- and RMS Doppler spread, we also highlight the importance of characterizing multipaths in the environment.**

***Index Terms*—Channel Sounding & Modeling, Delay-Doppler, Multipath Propagation, Polarization, Indoor Environment**

I. Introduction

Indoor radio channels are commonly characterized by multipath propagation phenomena such as reflection, diffraction, and scattering. Over time, movement of the transmitter, receiver and/or obstacles, will give rise to phase changes of the propagation paths. This broadens the frequency spectrum of the received signal, resulting in a frequency shift between the transmitted and received signal, which is an extra difficulty for the design of the receiver module in a wireless communication system. The delay-Doppler spectrum also influences the minimum required subcarrier-spacing as a function of the desired Signal-to-Interference ratio on any of the subcarriers [1].

The objective of this work is the analysis of delay-Doppler characteristics of a dynamic indoor environment at 3.6 GHz in a university-hall (see Fig. 1) during short and long breaks with varying occupation in-between courses. The novelty of our analysis is to investigate whether different measurement positions, as well as occupational densities, and polarization of the antennas, have an impact on the Doppler characteristics.

II. Measurements

A. Measurement environment

The indoor measurements were carried out during normal school hours (10h00-18h30) in a university-hall (see Figure 1) of the Catholic University of Louvain (UCL) in Louvain-la-Neuve, Belgium. The hall is approximately 22×17×3 meters, occupied at mostly by 200 people, and furnished with desks, chairs, and radiators. There are two main exits of the hall, both indicated on the left and right of the figure. Several smaller hallways lead to auditoriums of various sizes, indicated in blue and yellow. During each of the three measurement days, four blocks of 2 hour long courses were given in the auditoriums adjacent to the hall, all separated by a mandatory 'long' break. Some time before and after these courses, we can thus expect plenty of movement due to students switching courses, arriving or leaving, etc. During each course, a 'short' break of about 10 minutes was given optionally by the lecturers. These breaks are non-mandatory, and occur approximately half way during a class. Because they also vary in duration, we can thus expect fewer students per measurement cycle during these breaks.

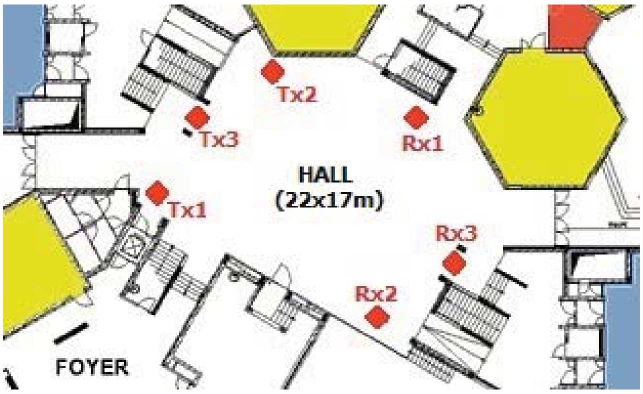

Figure 1: Measurement environment with the positions of the Tx-and Rx-antennas. Tx_1-Rx_1 is 15.26m, Tx_2-Rx_2 is 19.75m and Tx_3-Rx_3 is 18.16m

B. Channel sounding procedure

Indoor broadband measurements were carried out with an Elektrobit channel sounder at a carrier frequency of 3.6 GHz with a bandwidth of 200 MHz. At the transmitter (Tx) side, a horn antenna with both horizontal and vertical polarizations was used, whereas the receiver (Rx) side consisted of two 45° slanted patch antennas. The complex gains measured at these patches lets us recalculate both their H- and V-contributions, which enables us to estimate the full polarimetric channel.

III. Evaluation

In our analysis, 501 consecutive cycles (total MIMO-matrix combining all polarizations) of 315 channel impulse responses were combined in order to calculate a delay-Doppler spectrum. Each cycle captures about 8 ms of data, corresponding with a maximum measurable Doppler shift of ±125 Hz. The combination of 501 consecutive cycles thus represents 4 s of data, resulting in a Doppler frequency resolution of 0.5 Hz. To analyze the next combination of cycles, an overlap of 50% was taken. The power spectrum combining both delay (0 to 630 ns) and Doppler frequencies (-125 to 125 Hz) was then calculated by making use of the discrete Fourier transform. To determine the actual Doppler spread, one must then consider the range of Doppler frequency shifts over which the power spectrum is non-zero. Due to measurement uncertainties and noise generated by the sounder, this spectrum will never be truly zero. In our analysis, the Doppler spread is the frequency shift for when the power first drops below a certain threshold. This threshold was chosen to be the 75th percentile of all Doppler powers plus an additional 6 dB, to stay clear from the noisy part of the spectrum. Instead of just focusing on the Doppler spread alone, it is often more interesting to investigate the behavior of the RMS Doppler spread. This metric provides insight into the distribution of power, rather than just the width of the power spectrum, and can be calculated as follows [2]:

$$f_{D,RMS} = \sqrt{\frac{\int f_d^2 D(f_d) \mathrm{d} f_d}{\int D(f_d) \mathrm{d} f_d}}, \tag{1}$$

In this formula, f_d is the Doppler frequency shift at a given delay, and $D(f_d)$ is its corresponding Doppler power.

IV. Results

A. Influence of polarization on Doppler parameters

Fig. 2 shows the delay-Doppler spread for the full polarimetric channel, averaged over all short breaks in the Tx-Rx$_1$ link. In our analysis, e.g. 'HV' corresponds to the transmitted H-polarization, and the received (45° projected) V-polarization.

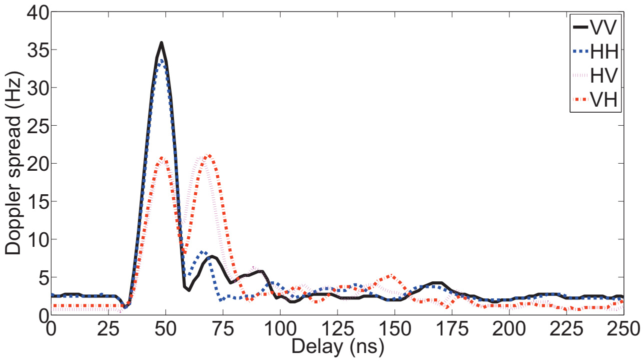

Figure 2: Median delay-Doppler spread estimate for the full polarimetric (VV, HH, HV, VH) radio channel. Configuration: Tx-Rx$_1$ link, short break.

When studying the first multipath component arriving at 50 ns, we measured Doppler spreads for both the VV- and HH-polarizations of approximately 36 Hz, corresponding with a velocity v of about 5.4 km/h according to $f_D = \frac{2v}{\lambda}$ [2]. These values correspond quite well for moving persons.

The Doppler values for the two co-polarizations (VV and HH) differ quite strongly with those of both cross-polarizations (HV and VH), which were only about 20 Hz, or the equivalent of 3 km/h. We can thus state that there is a significant difference between the Doppler characteristics of co- and cross-polarizations. However, looking at the second multipath component arriving at 70 ns, the cross-polarizations still results in Doppler spreads that are comparable with those of the first ones, whereas the co-polarizations only reaches values of 8 Hz. This could originate from the lack of antenna de-embedding.

B. Summary of the measurement results

Table I lists an analysis of the Doppler- and RMS Doppler spreads for the full polarimetric radio channel. Values in the table represent the maximum in the delay domain of the median estimated response per polarization in the Tx-Rx$_1$ link.

		VV	**HH**	**HV**	**VH**
$\mathbf{f_D}$	short	35.93 Hz	33.56 Hz	20.71 Hz	21.21 Hz
	long	25.82 Hz	24.70 Hz	13.60 Hz	13.22 Hz
$\mathbf{f_{D,RMS}}$	short	9.31 Hz	8.84 Hz	6.39 Hz	6.45 Hz
	long	17.25 Hz	16.33 Hz	8.72 Hz	8.18 Hz

Table I: Comparison of Doppler- and RMS Doppler spreads (Hz) for the full polarimetric indoor radio channel, throughout various short and long breaks.

From this table, we can conclude that there is a significant difference between both the short and long breaks in-between courses. Looking at the short breaks, their Doppler spreads always result in higher values than the long breaks. This indicates that on average, people move faster during these kind of breaks. More noticeable, their RMS value is compellingly lower than during the long breaks, indicating that the Doppler power is firmly concentrated towards the center of the spectrum. This is quite intuitive, since during the long breaks there are a lot of people present in the channel, each having their own different speed and orientation towards the antennas. We can also notice that the co-polarizations (VV and HH) tend to result in broader Doppler- and RMS Doppler spreads than the cross-polarizations (HV and VH).

V. Conclusions

In this work, an analysis of delay-Doppler characteristics in the presence of moving people is presented for short-range communications at 3.6 GHz in a crowded university-hall. The measurements indicate the importance of analyzing the RMS Doppler spread between low and high occupation in-between courses. We also demonstrate that there is a significant difference between the Doppler characteristics of the transmitted co- and cross-polarizations. We also highlight the importance of characterizing multipath behavior in the environment.

Future work includes a further enhancement of the COST 2100 channel model [3] with the effect of Doppler characteristics for user motion, since this model currently only takes receiver motion into account. Next to that, the effect of antenna de-embedding will be evaluated, as well as the influence of different measurement positions in the environment.

Acknowledgment

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